1

SEMICONDUCTOR RECTIFIERS AND D.C. POWER SUPPLIES

Preliminaries of rectification

The process of converting a.c voltage into d.c voltage is known as rectification.

A device which converts a.c voltage into d.c voltage is called a rectifier.

Three types of rectifier circuits

(i) Half-wave rectifier

(ii) Full wave rectifier (using two diodes)

(iii) Bridge rectifier (full wave - using four diodes)

A full wave rectifier (FWR) has rectifier efficiency (η) twice that of half wave rectifier (HWR). FWR has low ripple voltage and high ripple frequency. So the expense towards the filter circuit for FWR is less.

Bridge rectifier

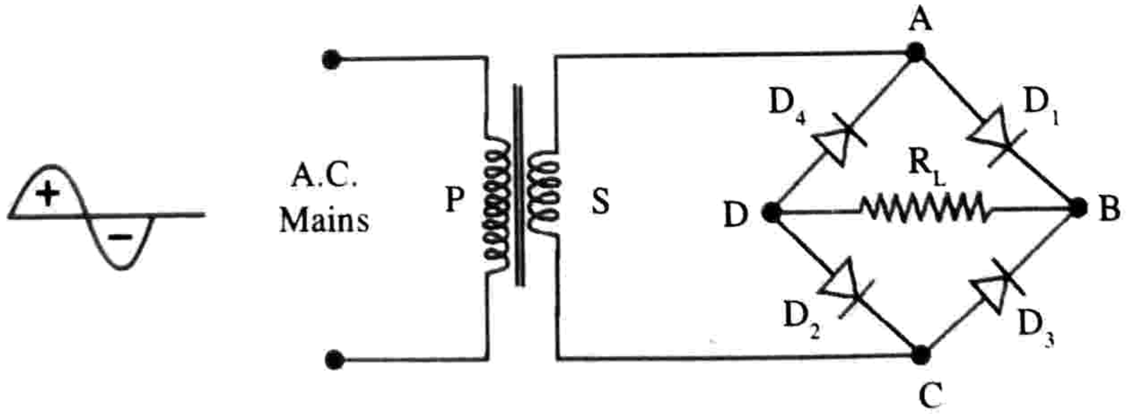

Fig. 1.1

It consists of four diodes D_1, D_2, D_3 & D_4 connected in the form of a bridge ABCD. Between D and B load resistance R_L is connected. The secondary terminals of the transformer are connected to A and C.

Input voltage of A.C mains $\mathbf{V = V_m \sin \omega t}$

During the +ve half cycle, the terminal A becomes +ve and C becomes negative. Now diodes D_1 and D_2 are forward biased and act as shorts. Now diodes D_3 and D_4 are reverse biased and hence act as open.

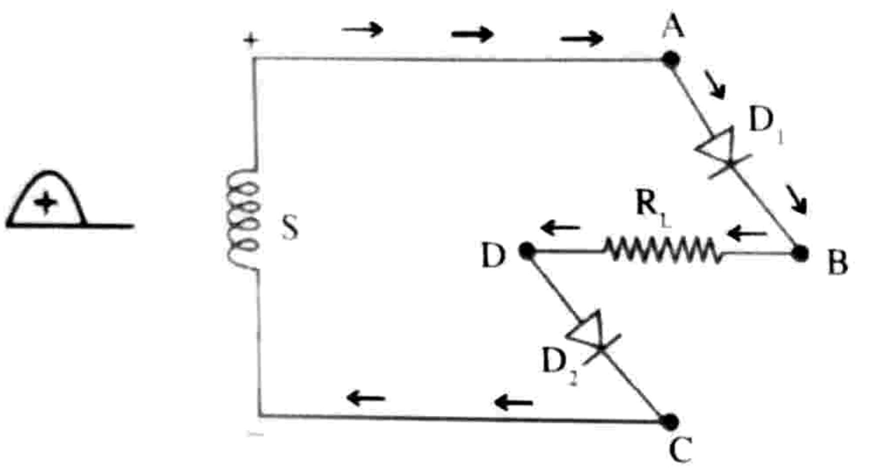

Fig. 1.2

During the –ve half cycle, the terminal A becomes –ve and C becomes +ve. Now diodes D_1 and D_2 are reverse biased and act as open. Diodes D_3 and D_4 are forward biased and act as short.

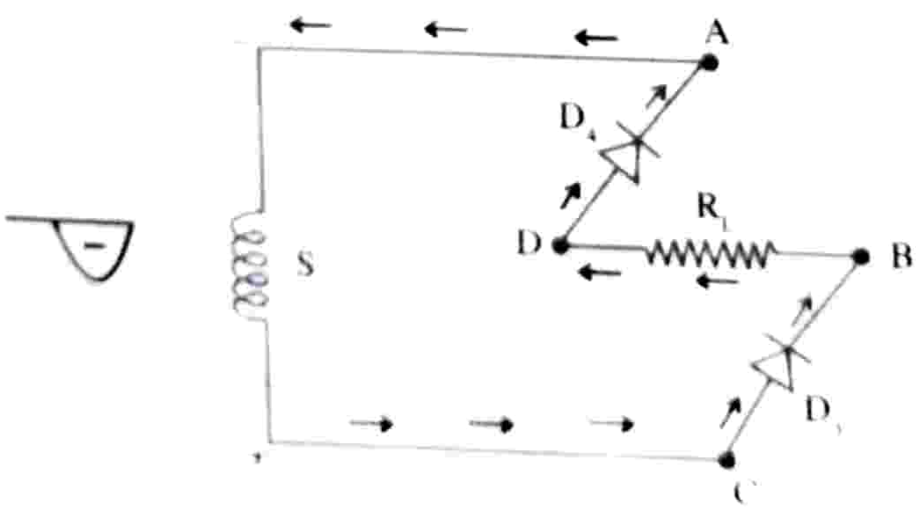

Fig. 1.3

So during both halves of the input cycle, there is output voltage. The rectifier is therefore a full-wave rectifier. Output voltage is uni-directional through R_L.

Nature of rectified output

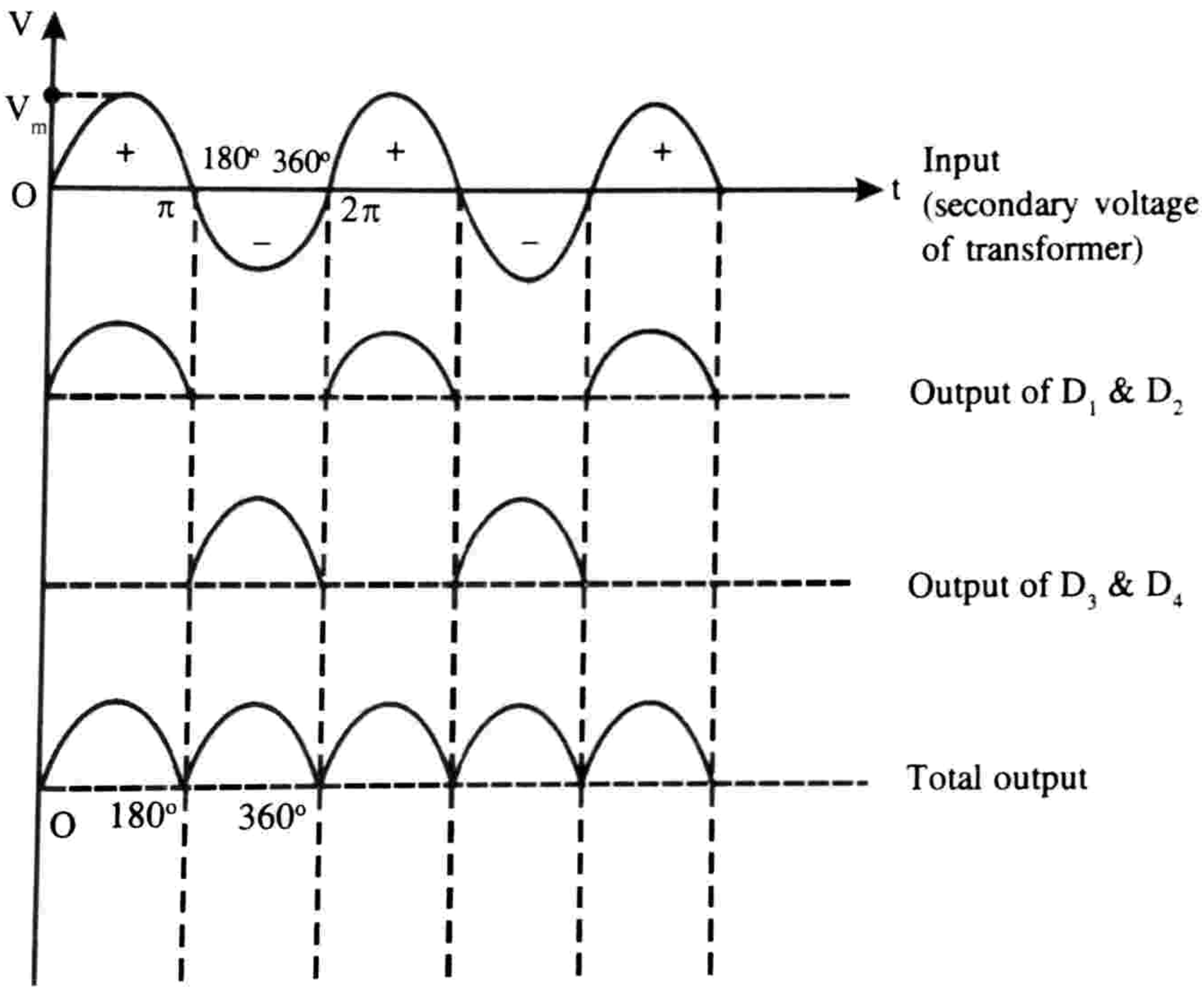

Fig. 1.4

PIV

(CU Nov. 2020)

PIV is the peak inverse voltage. It is the maximum voltage across the reverse biased diode of a rectifier. This voltage must be less than the breakdown voltage of the diode otherwise the diode will be destroyed.

Compare HWR and FWR

Table 1.1

Wave forms →			
Measure of performance	HWR	FWR	Bridge
Number of diodes used	1	2	4
Is transformer necessary?	No	Yes	Yes
Line to line secondary voltage	$\frac{V_m}{\sqrt{2}}$	$\frac{2V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
PIV	V_m	$2V_m$	V_m
V_{dc}	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
I_{dc}	$\frac{I_m}{\pi}$		$0.636\ I_m = 0.9\ I_{rms}$
I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
Ripple factor (r)	1.21	0.482	0.482
Ripple frequency	f_i (frequency of input voltage)	$2f_i$	$2f_i$

Problem

1. *Compare halfwave and full wave rectifiers* *(CU Nov 19)*

Advantages

1. No centre tap is required for transformer.
2. All the secondary voltage is used as the input to the rectifier. Output voltage is twice that of centre tap FWR. So this can be used for high voltage applications.
3. Peak inverse voltage (PIV) across each diode is equal to the peak value of the transformer secondary voltage $(-V_m)$. So PIV is half that of FWR centre tap circuit, which is $(-2V_m)$. [PIV is the

peak voltage appearing across the diode during –ve half cycle. i.e., during π to 2π].

4. Transformer utilization factor for a bridge circuit is higher than that of a centre tap FWR. So bridge circuit can be used where a larger dc power is required.

Disadvantages

1. It requires two extra diodes. Current flows through two diodes in series during each half-cycle of input a.c. So there will be more voltage drop and power dissipation in the internal resistance of the diodes.
2. Its regulation is relatively poor.

Problem

2. *A diode with $V_F = 0.7V$ is connected to as a HWR. The load resistance is 500Ω and the (r.m.s.) as input is 22V. Determine the peak output voltage, the peak load current and the diode peak inverse voltage* *(CU Nov. 18)*

Ans : Peak input voltage = $\sqrt{2} \times V_i = 1.414 \times 22 = 31.1V$

Peak output voltage = Peak input voltage–$V_F = 31.1 - 0.7 = 30.4V$

$$\text{Peak load current} = \frac{\text{Peak output voltage}}{R_L} = \frac{30.4}{500} = 60.8\text{mA}$$

PIV = Peak input voltage = 31.1V.

Efficiency of FWR

$$V = V_m \sin \omega t = V_m \sin \theta$$

$$i = \frac{V}{r_f + R_L} = \frac{V_m \sin\theta}{r_f + R_L}$$

$$\text{d.c. output power } P_{dc} = I_{dc}^2 \times R_L$$

$$= \left(\frac{2I_m}{\pi}\right)^2 \times R_L$$

a.c. input power $P_{ac} = I_{rms}^2 (r_f + R_L)$

r_f = forward resistance of the diode

For a full-wave rectified wave,

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\therefore \quad P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)$$

Full-wave rectification efficiency $\eta = \dfrac{P_{dc}}{P_{ac}} = \dfrac{(2I_m/\pi)^2 R_L}{\left(\dfrac{I_m}{\sqrt{2}}\right)^2 (r_f + R_L)}$

$$= \frac{8}{\pi^2} \times \frac{R_L}{(r_f + R_L)} = \frac{0.812\, R_L}{r_f + R_L} = \frac{0.812}{1 + \dfrac{r_f}{R_L}}$$

η is maximum when $r_f << R_L$

$\therefore \quad \eta = 0.812 = 81.2$ % (double the efficiency due to HWR)

Problem

3. *What is the maximum efficiency at a FWR?* *(CU Nov. 20)*

Ans : 81.2%

Ripple Factor

The output of a rectifier contain a d.c component as well as an a.c component (which is called ripple). Smaller this ripple, more effective is the rectifier.

$$\text{ripple factor } (\mathbf{r}) = \frac{\text{r.m.s value of a.c component}}{\text{value of d.c component}}$$

$$\text{Ripple factor of FWR } (\mathbf{r}) = \left[\frac{V_{rms}{}^2}{V_{dc}{}^2} - 1\right]^{1/2} = 48.2\% \text{ (or) } 0.482$$

A measure of the purity of d.c. output is the ripple factor (r). It is the ratio of the two current or voltage components.

$$r = \frac{\text{r.m.s. value of a.c component}}{\text{d.c component}}$$

$$= \frac{I_{ac}}{I_{dc}} = \frac{(I_r)_{rms}}{I_{dc}} = \frac{(V_r)_{rms}}{V_{dc}} \qquad \text{..... (1)}$$

$$I_{rms}^2 = I_{dc}^2 + (I_r)_{rms}^2 \qquad \because I_r = \text{ripple current}$$

$$\therefore \qquad r = \frac{(I_r)_{rms}}{I_{dc}}$$

$$= \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

$$= \sqrt{\frac{I_{rms}^2 - I_{dc}^2}{I_{dc}^2}} = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1}$$

$$r = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

For FWR, $I_{rms} = \frac{I_m}{\sqrt{2}}$

$$I_{dc} = \frac{2I_m}{\pi}$$

Substituting

$$r = \sqrt{\left(\frac{\frac{I_m}{\sqrt{2}}}{\frac{2I_m}{\pi}}\right)^2 - 1}$$

$$r = \sqrt{\frac{\pi^2}{8} - 1} = 0.48$$

i.e., amount of a.c. voltage present in the output is 48% of the d.c. voltage.

But for HWR $r = 1.21$

It is the ratio of the two current or voltage components.

Problems

4. *What is ripple factor ?* *(CU Nov. 19)*

5. *What is the ripple factor of a FWR ?* *(CU Nov. 18)*

   Ans : 0.482

6. *Draw the circuit diagram and explain the working of a full wave bridge rectifier. Also derive an expression for I_{dc}, I_{rms}, PIV, ripple factor and efficiency* *(CU Nov. 18)*

   Hints : Circuit diagram-working – Derivations for I_{dc}, I_{rms}, PIV, r and η

Filtering

The process of removing the ripples in the rectifier output.

Filter Circuits

A device which removes the ripple or a.c component in the rectifier output. It allows the d.c component to reach the load.

In radio recievers, the excessive ripple in the audio signal produces 'hum'. To remove this filtering is needed.

Filter circuit is connected across the output or before the load (R_L)

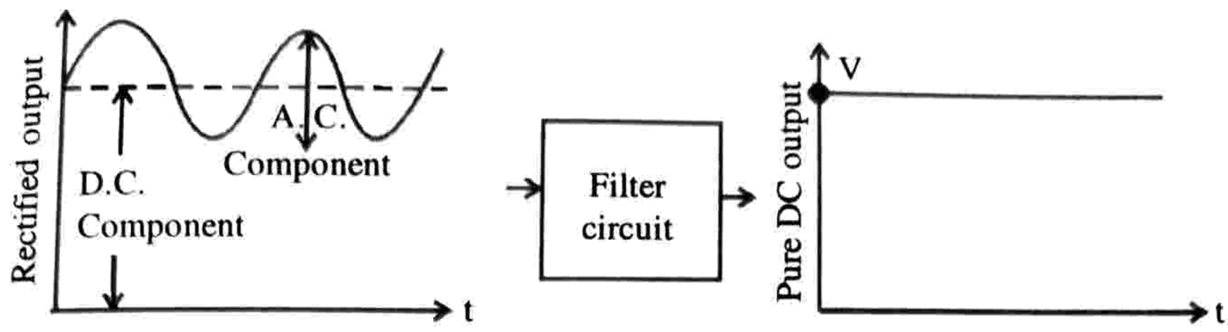

Fig. 1.5

Different types of filter circuits

1. Capacitor filter

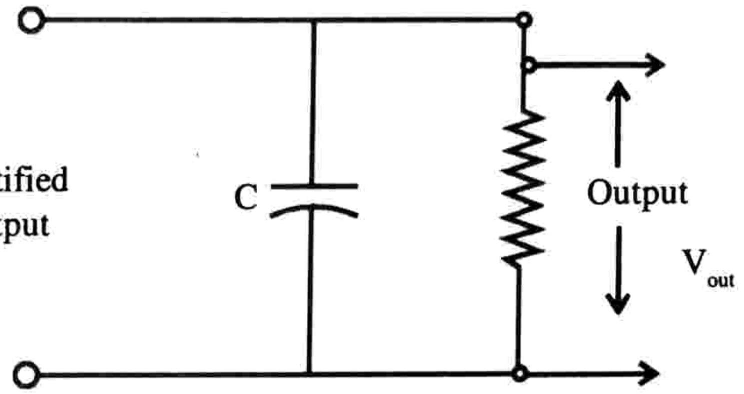

Fig. 1.6

Capacitor C is connected in parallel with the load R_L. Capacitor offers a low reactance path to a.c. component $\left(\because \text{capacitive reactance } X_C = \frac{1}{\omega c} = \frac{1}{2\pi fc}\right)$. For d.c., frequency $f = 0$. Hence capacitor blocks d.c. So all the d.c. component passes through the load. Only very small a.c. component reaches at R_L. So ripple voltage is very small.

As the diode conducts, C gets charged fully. It stores electrical energy. Its voltage attains peak value of the input voltage. Capacitor charges up (stores energy) when the diodes are conducting and discharges during the non-conducting cycle.

During +ve half cycle, the diode is forward biased and ON. This allows C to quickly charge up to V_m (at B). Now the rectifier voltage starts to decrease. Capacitor discharges through the load R_L and voltage across it decreases slightly (as shown by the line BC). Immediately the next voltage peak comes. Capacitor again gets charged. This process repeats. ABCDE gives the voltage waveform. It is not a straight line. Because very little ripple is left there. Capacitor filter has low cost, small size, little weight and good characteristics.

T_1 = Time for charging

T_2 = Time for discharging

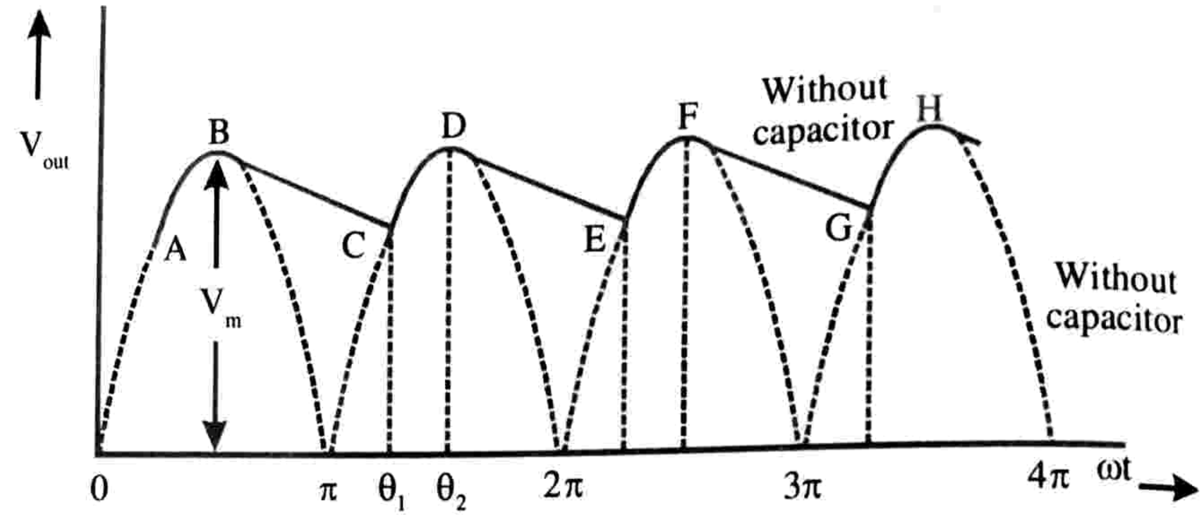

Fig. 1.7(a)

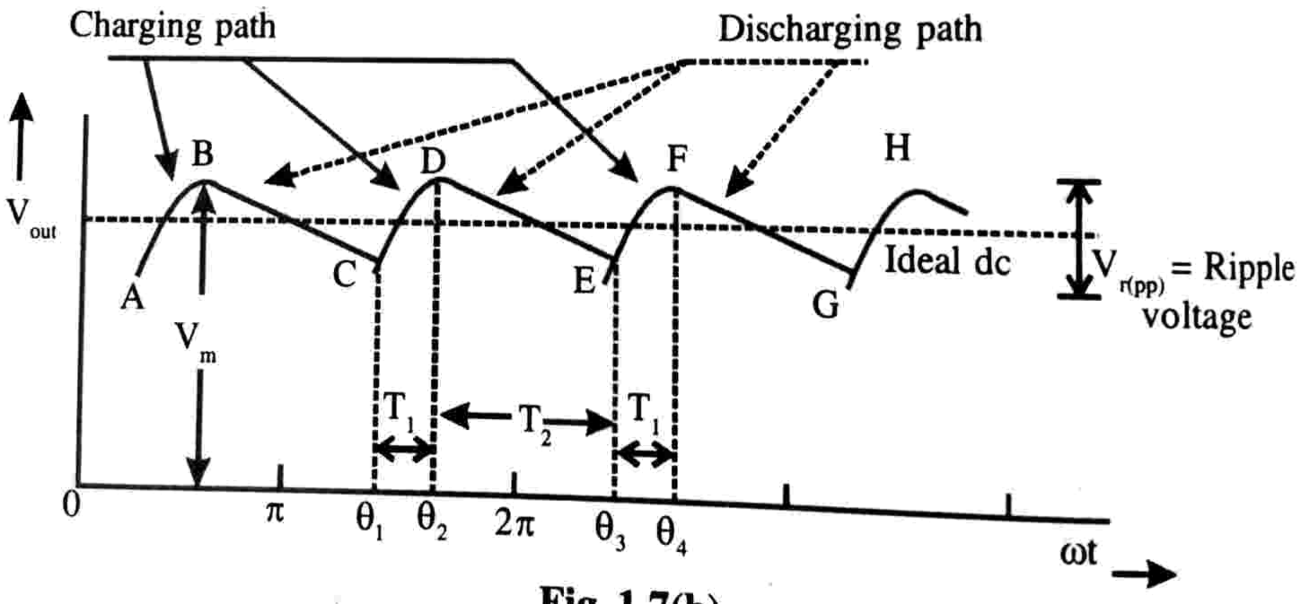

Fig. 1.7(b)

T_1 is the time for charging & T_2 is the time for discharging.

In the absence of the capacitor, the voltage across R_L would have fallen and followed the path shown by dashed curve in fig. 1.7(a). During discharging path through R_L, it discharges exponentially. (The discharging depends on the time constant RC)

$$\text{ripple factor} \quad r = \frac{2410}{CR_L} \quad \text{for } f = 60\text{Hz}$$

2. Inductor filter or L-filter

Inductor filter consists of choke (inductance) L in series with load R_L.

The characteristic of an inductance is to oppose the flow of ripple or alternating current through it due to its reactance $(X_L = 2\pi fL)$. At the same time it allows dc component to pass through. Because inductance has very low resistance.

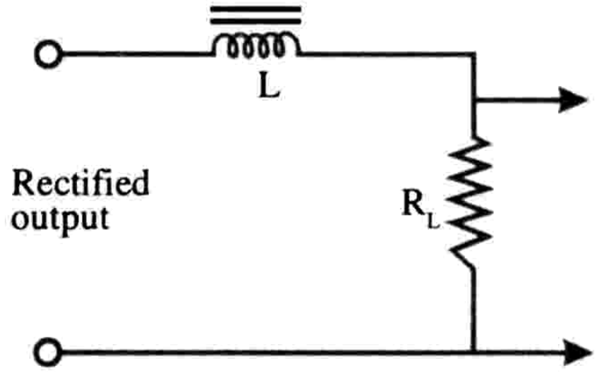

Fig. 1.8

The inductance stores energy in the form of magnetic energy. It releases this energy when the output across the load decreases. By doing this output is smoothening.

$$\text{ripple factor } r = \frac{R_L}{1600\,L} \quad \text{for } f = 60\text{Hz}$$

3. Choke input filter or L-C filter

Ripple factor increases with an increase in load in case of L - filter. But decreases in case of C - filter when C is kept constant. So a combination of the above two filters called choke input filter or L.C. filter section makes ripple independent of the load R_L.

Choke offers high opposition to the passage of a.c. component. (inductive reactance $X_L = 2\pi f\,L$). But negligible opposition to d.c. component. In figure 1.9 at the point **a**, the rectifier output contains almost d.c. component. Remaining part of a.c. component passes through the capacitor C which prevents the d.c. component to flow through it.

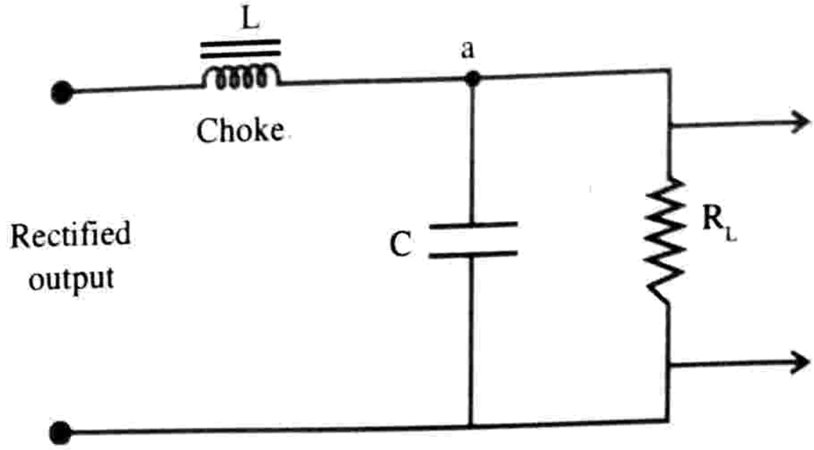

Fig. 1.9

$$\text{ripple factor } r = \frac{0.83}{LC} \quad \text{for } f = 60\text{Hz}$$

4. Capacitor input filter (or) π-filter or CLC filter

C_1 & C_2 are filter capaictors. L is a choke. Capacitor C_1 bypasses a.c. components. Remaining part passes through choke L. Choke permits dc components. The remaining ripple is filtered by C_2.

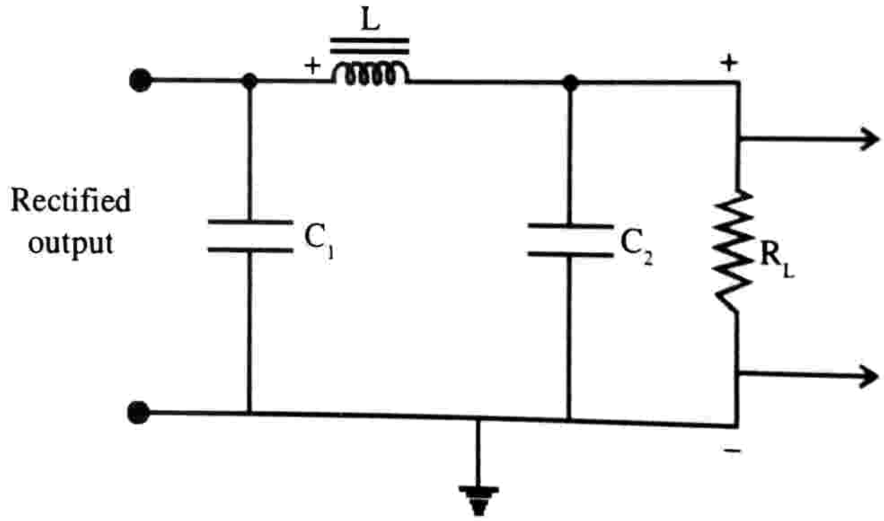

Fig. 1.10

Problem

7. *What are filters? with the help of diagrams explain the working of shunt capacitor and LC filter circuit.* *(CU Nov. 20)*

Voltage Multipliers

A voltage multiplier is an electrical device that converts ac electrical power from lower voltage to higher dc voltage. For this diodes and capacitors are used.

Dis advantage : The line voltage is only 50Hz. So large inductances have to be used to get enough reactance for sufficient filtering. But large inductors have large resistances. So large dc voltage drop occurs across the inductor.

They are classified into – voltage doublers, voltage triplers and voltage quadruplers. Each is again divided into Half wave and full wave.

Half-wave voltage doubler

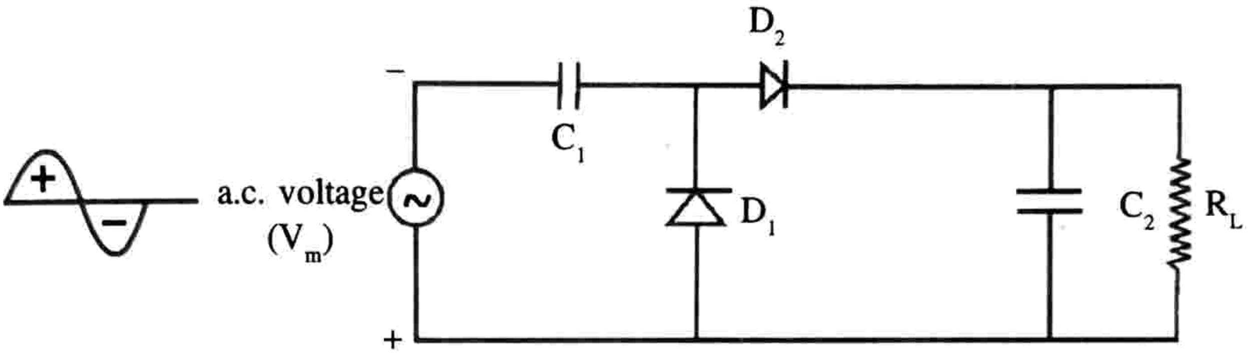

Fig. 1.11

Consider the –ve half-cycle of a.c. input voltage. D_1 is forward biased. D_2 is reverse biased. So D_1 is represented by a short and D_2 by open. Current flowing through the diode D_1 charges the capacitor C_2 up to the peak value of input voltage V_m

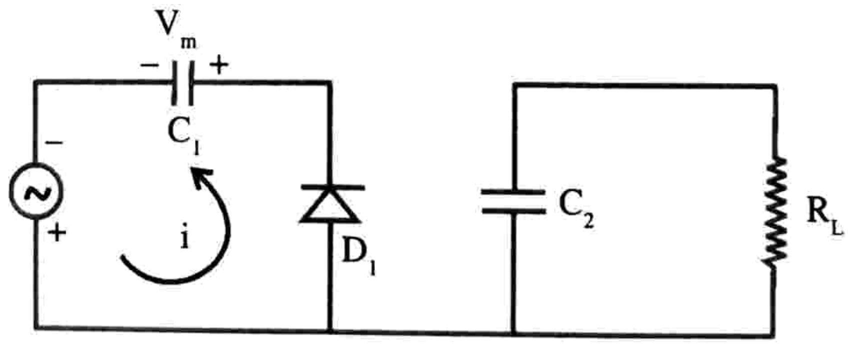

Fig. 1.12

Consider the +ve half cycle of a.c input voltage. Now D_2 is forward biased and D_1 is reverse biased.

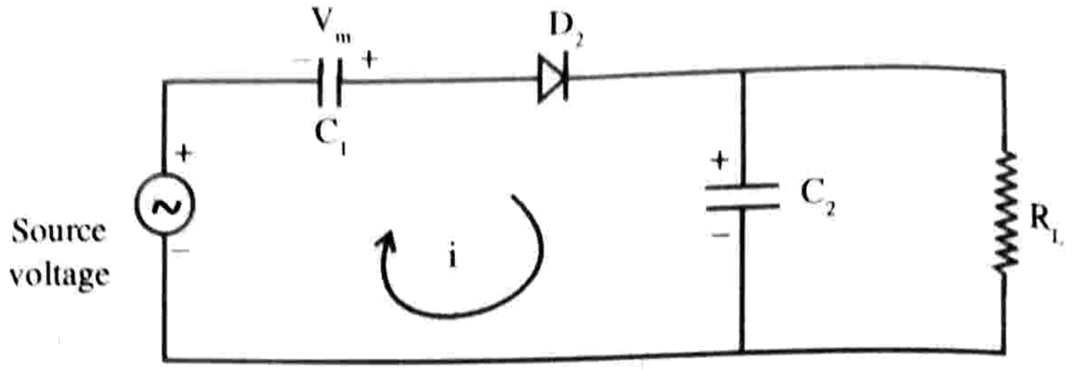

Fig. 1.13

Current flows through D_2 charges capacitor C_2. i.e., C_1 is in series with voltage across source secondary voltage. There exists a series circuit comprising C_1, D_2 and C_2. This action of series aiding is comparable to the connection of two dry batteries each of voltage V_m.

So, after one complete cycle of input voltage, we get a voltage across C_2 which is just double of the peak value of input voltage.

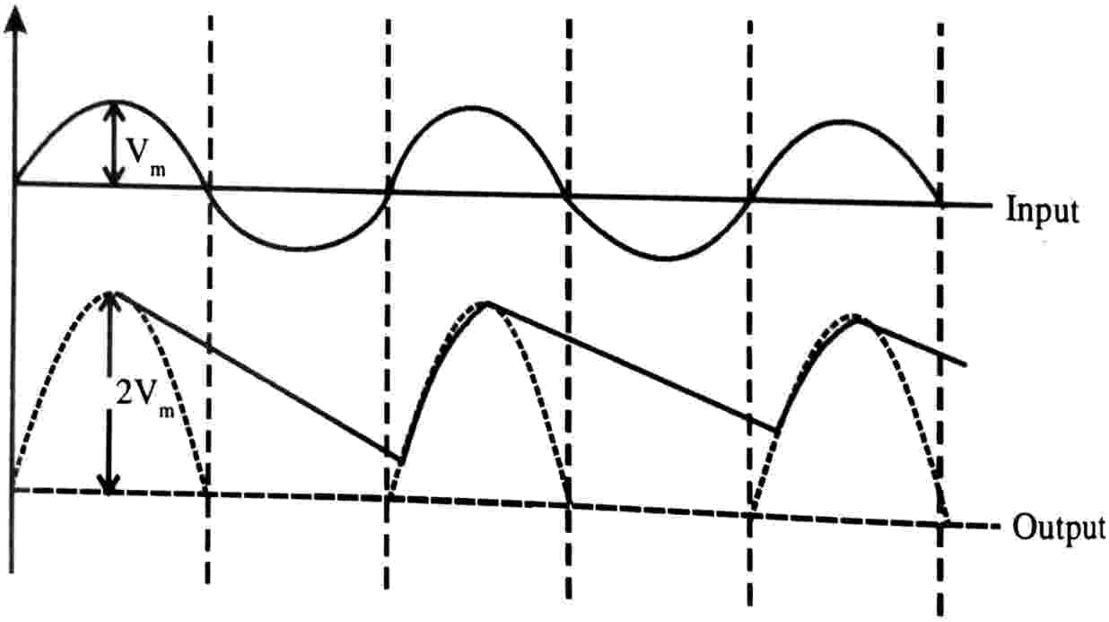

Fig. 1.14

Disadvantage

Poor voltage regulation. As the load current increases output voltage drops. So large filter capacitors are needed.

Problems

8. *Why voltage multiplier is better than to use a transformer with a higher turns ratio and an ordinary rectifier?*

Ans: At lower voltage, transformer is better than voltage multiplier. But for higher voltages, voltage multiplier is desired. Consider the line voltage is 200V peak. If the voltage to be produced is 4000V, we have to use 1:20 step-up transformer. Such transformer will be bulky. It is not possible.

9. *Draw the circuit diagram and explain the working of a voltage multiplier circuit* *(CU Nov. 18)*

Zener diode

Zener diodes are made of Silicon. Here doping of impurity atoms ($1:10^4$) is different from ordinary p-n junction diode ($1:10^6$). Zener diodes operate in the breakdown region. They are used for voltage regulation. Because breakdown voltage is nearly constant for a large variation of current. It can sustain heavy current at zener breakdown region.

The symbol for zener diode is

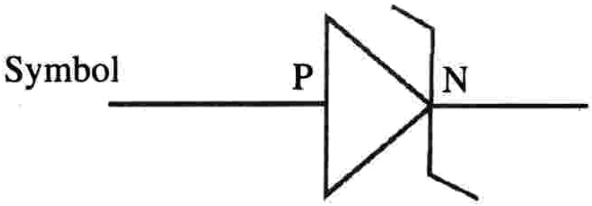

Fig. 1.15

Zener is like an ordinary diode. It is properly doped for a sharp breakdown at breakdown voltage. V_Z. It is always reverse biased. During forward bias it behaves like an ordinary diode.

Characteristics of zener diode is as follows.

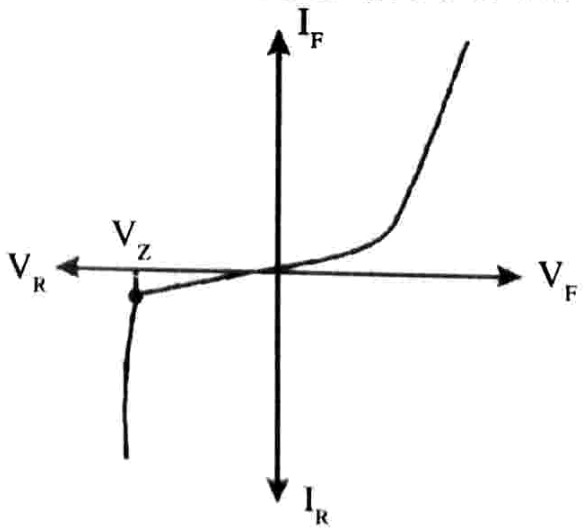

Fig. 1.16

The reverse characteristic of zener diode is as follows.

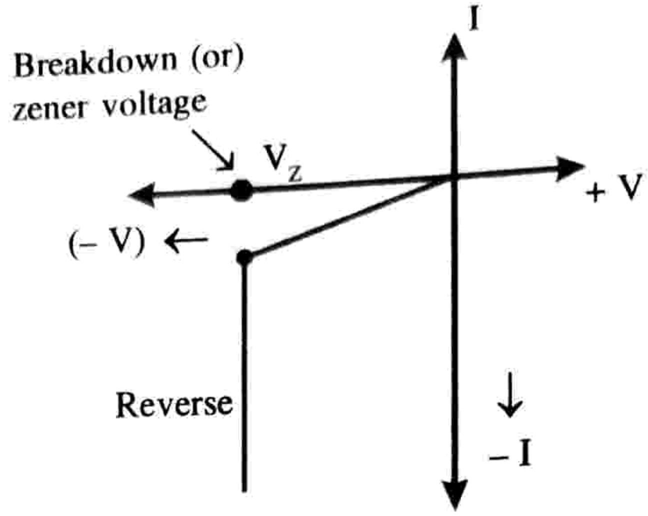

Fig. 1.17

Breakdown

i) Avalanche breakdown

When reverse bias voltage is applied, minority carriers acquire sufficient energy. Due to this energy valence electrons are removed from the covalent bonds and new charge carriers are produced. These are accelerated. It also acquire sufficient energy which produces additional charge carriers by collision with host atoms. This process repeats and multiplies. A chain reaction is produced. This results in a large reverse current. This fakes place at high reverse voltages.

ii) Zener breakdown

Zener breakdown takes place in junctions which are heavily doped. The heavily doped junctions have a narrow depletion layer. The electric field at the junction increases when the reverse voltage increases. The strong electric field produced causes a breakage of covalent bond, from the crystal structure. Due to this a large number of minority carriers are generated. So a large current flows through the junction.

Zener breakdown occurs at heavily doped junction.

Equivalent circuit of Zener diode

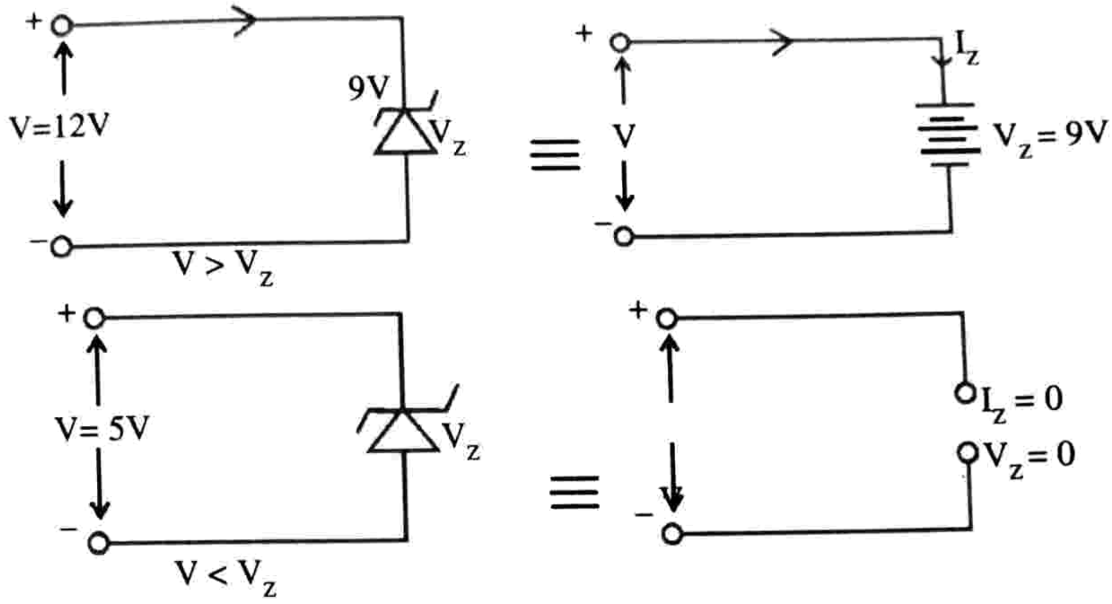

Fig. 1.18

Voltage stabilisation

Zener diode as voltage stabiliser

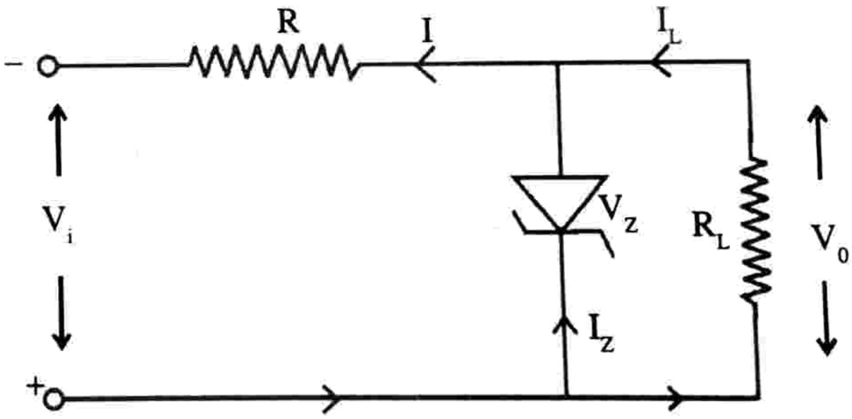

Fig. 1.19

Zener diode is equivalent to a battey V_Z.

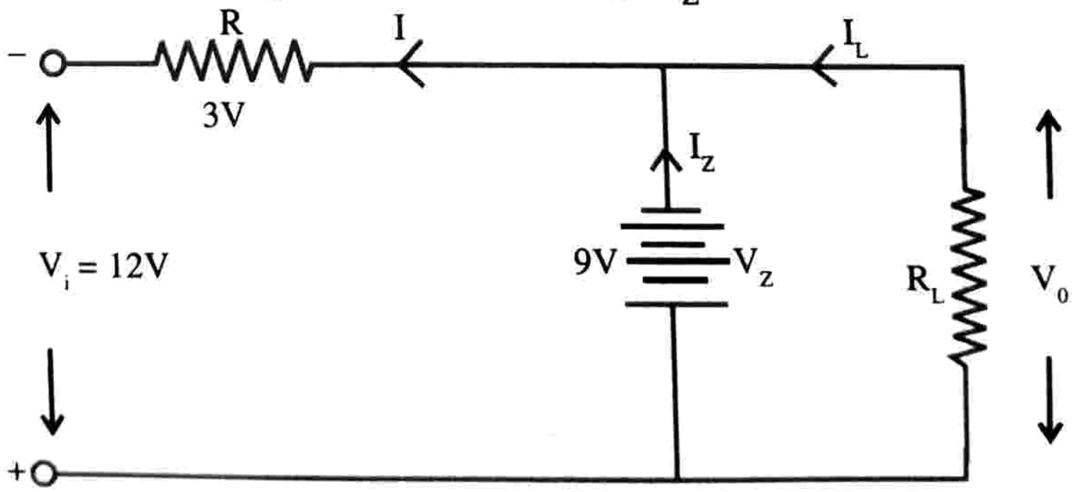

Fig. 1.20

The output voltage remains constant at $V_z = V_0$. When the input voltage $V_i > V_z$, the excess voltage is dropped across the series resistor R. This produces an increase in the value of total current I passing through R and zener diode. This increases the voltage drop across R without any change in the voltage across zener diode. This is because in the breakdown region, zener voltage remains constant even though the current through the zener diode changes.

Consider another case in which input voltage is constant. But load resistance R_L decreases. So I_L increases.

Voltage across R, $(IR) = V_i - V_0$ $\qquad (V_z = V_0)$

Current through R, $I = I_z + I_L$ $\qquad$ (using KCL)

$$\therefore \quad IR = V_i - V_0$$

$$(I_z + I_L)\, R = V_i - V_0$$

$$R = \frac{V_i - V_0}{I_z + I_L}$$

10. Explain how voltage stabilisation is ensured in a zener diode voltage regulator *(CU Nov. 20)*

Assignments

1. Consider a zener diode of $V_Z = 6$ V. The load current is 4mA. The unregulated input of this regulator is 10V. Find R?

   Choose zener current as 5 times the load current

$$I_z = 5 \times 4 = 20 \text{ mA}$$

using KCL at **a**, $\qquad I = I_z + I_L = 20 + 4 = 24 \text{ mA}$

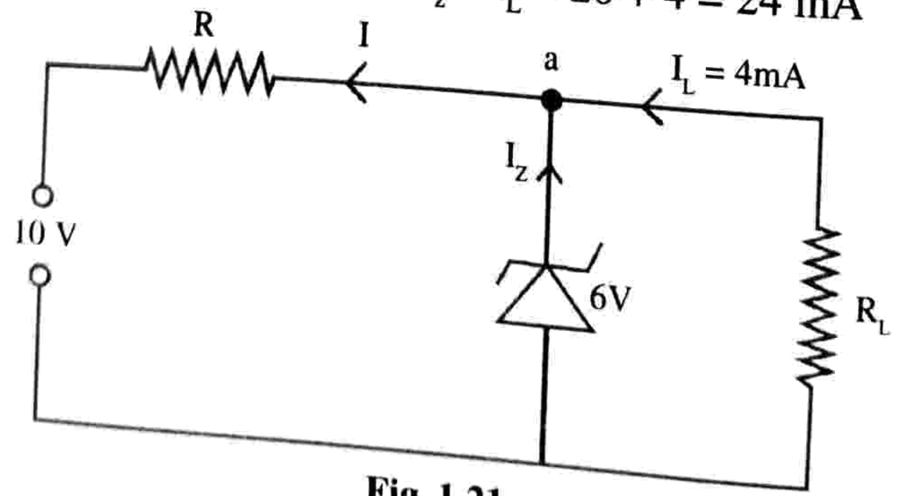

Fig. 1.21

$\therefore$ IR drop across $R = 10\text{ V} - 6\text{V} = 4\text{V}$

i.e., $24 \times 10^{-3} \times R = 4$

$$R = \frac{4 \times 10^3}{24} = \mathbf{167\Omega}.$$

2. The Four diodes used in a bridge rectifier circuit have forward resistances which may be considered constant at 1Ω and infinite reverse resistance. The alternating supply voltage is 240 Vr.m.s. and load resistance is 480Ω. Calculate (i) Mean load current and (ii) Power dissipated in each diode. (CU 2017 Nov.)

Ans: Maximum AC voltage, $V_{in} = 240 \times \sqrt{2}$

(i) At any instant, two diodes in series are conducting.

$\therefore$ Total circuit resistance = $2 \times r + R_L$

$$I_m = \frac{V_m}{2r + R_L} = \frac{240 \times \sqrt{2}}{2 \times 1 + 480} = 0.7\text{A}$$

$$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 0.7}{3.14} = 0.45\text{A}$$

(ii) Each diode conducts only half a cycle.

Diode r.m.s. current is $I_{rms} = \frac{I_m}{2} = \frac{0.7}{2} = 0.35\text{A}.$

Power dissipated in each diode

$= I_{rms}^2 r_f = (0.35)^2 \times 1 = 0.123\text{W}.$

3. A FWR uses input capacitor filter. $R_L = 8\text{k}\Omega$. $C = 10\mu\text{F}$. Applied peak voltage is 400V, 60Hz. Total variation in capacitor voltage $(V_r)_{pp}$ = 10V. Calculate a) Output dc voltage b) ripple factor.

Ans: a) $E_m - E_{dc} = \frac{(V_r)_{pp}}{2}$

$$E_{dc} = E_m - \frac{(V_r)_{pp}}{2}$$

$\therefore$ IR drop across $\quad R = 10\text{ V} - 6\text{V} = 4\text{V}$

i.e., $\quad 24 \times 10^{-3} \times R = 4$

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Power dissipated in each diode

$$= I_{rms}^2 r_f = (0.35)^2 \times 1 = 0.123\text{W}.$$

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Ans: a) $E_m - E_{dc} = \dfrac{(V_r)_{pp}}{2}$

$$E_{dc} = E_m - \frac{(V_r)_{pp}}{2}$$

$$= 400 - \frac{10}{2} = \underline{\underline{395V}}$$

b) $$r = \frac{2410}{CR_L} = \underline{\underline{0.03}}$$

4. For constructing a FWR of 10V at 100mA, construct L-C- filter with 2% ripple factor. Calculate the values of load resistance and capacitance, if 1 Henry coil is used?

Ans: $$r = 2\% = \frac{2}{100} = 0.02$$

$$E_{dc} = I_{dc} R_L$$

$$R_L = \frac{E_{dc}}{I_{dc}} = \frac{10}{100 \times 10^{-3}} = 100\Omega$$

$$r = \frac{0.83}{LC}$$

$$0.02 = \frac{0.83}{1 \times C}$$

$$C = \frac{0.83}{0.02} = \frac{83}{2} = 41.5\mu F$$

5. The source voltage of a loaded voltage regulator is 12V. A series resistor of 270Ω is connected. Load resistor $R_L = 1k\Omega$. Voltage of zener diode $V_Z = 6V$. Calculate zener current.

Ans: $$I_S R_S = V_i - V_Z$$

$$I_S = \frac{V_i - V_Z}{R_S}$$ (S stands for series and L for load)

$$= \frac{12-6}{270} = \frac{6}{270} = \frac{2}{90}$$

$$= 0.222\text{A}$$

$$= 22.2\text{mA}$$

Load current $I_L = \frac{V_Z}{R_L} = \frac{9}{1 \times 10^3}$

$$= 10^{-3}\text{A} = 10\text{mA}$$

Zener current $I_Z = I_S - I_L$

$$= 22.2 - 10 = 12.2\text{mA}$$

6. In a voltage regulator circuit using a 12V zener, series resistor of 330Ω and a load $1.5k\Omega$. Calculate the voltage across load (i) when zener diode is present (ii) when zener diode is disconnected (The source voltage is 20V)

(Ans: 20V, 16.9V)

7. For a zener shunt regulator if $V_Z = 10\text{V}$, $R_S = 1k\Omega$, $R_L = 2k\Omega$ and the input voltage varies from 22 to 40V. Find the maximum and minimum values of zener current.

$$I_L = \frac{V_0}{R_L} = \frac{10}{2 \times 10^3} = 5\text{mA}$$

$$I_{Z(max.)} = \frac{V_{i(max)} - V_Z}{R_S} - I_{L(min)}$$

$$= \frac{40-10}{1 \times 10^3} - 5 \times 10^{-3} = 25\text{mA}$$

$$I_{Z(mini)} = \frac{V_{i(mini)} - V_Z}{R_S} - I_{L(max)}$$

$$= \frac{22-10}{1 \times 10^3} - 5 \times 10^{-3} = 7\text{mA}$$

8. A 9V zener diode is used in a voltage regulation circuit. The load current is to vary from 10 to 100mA. Find the value of series resistance (R_S) to keep a voltage of 6V across the load. The input voltage is constant at 10V and the minimum zener current is 10mA.

Ans: $[I_{Z(min)} + I_{L(max)}]R_S = V_i - V_0$

$$R_S = \frac{V_i - V_0}{I_{Z(min)} + I_{L(max)}} = \frac{10-9}{10\times10^{-3} + 100\times10^{-3}}$$

$$= \frac{1}{110\times10^{-3}} = \frac{1000}{110} = 9\Omega$$

9. What value of series resistance R_S is required when two 10W, 10V, 1000mA zener diodes are connected in series to obtain 20V regulated output from a 50V dc power source?

Ans:

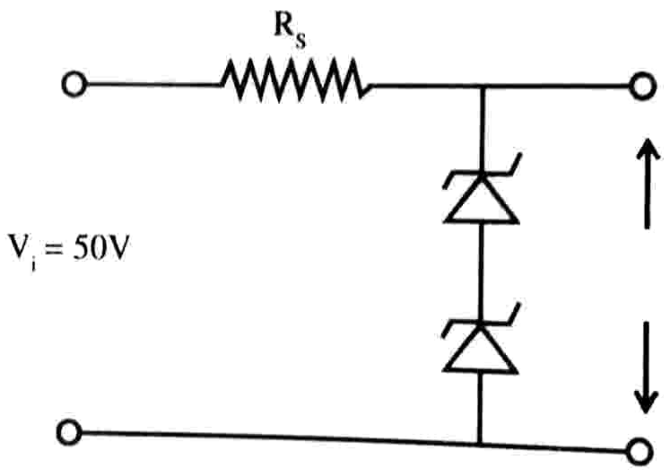

Fig. 1.22

$$V_0 = 2V_Z = 2\times10 = 20V$$

Voltage drop across $R_S = V_i - V_0$

$$= 50 - 20 = 30V$$

$$\therefore \quad R_S = \frac{30V}{I_{Z(max.)}} = \frac{30}{1000\times10^{-3}} = \frac{30000}{1000}$$

$$= 30\Omega$$

10. DC output voltage is 40V at full load and 41V without any load. Calculate the percentage load regulation factor.

Ans: % load regulation factor

$$= \frac{V_{\text{No load}} - V_{\text{Full load}}}{V_{\text{Full load}}} \times 100$$

$$= \frac{41-40}{40} \times 100$$

$$= \frac{1}{40} \times 100 = 2.5\%$$

11. A zener diode of 12V is connected as shown in fig. Source voltage is 20V. Calculate zener current.

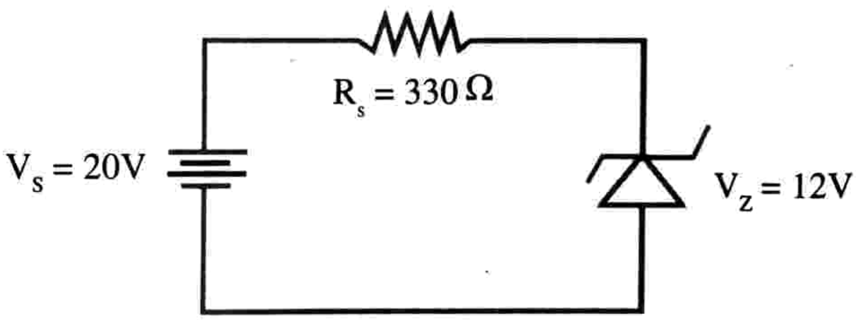

Fig. 1.23

$$I_Z = \frac{V_S - V_Z}{R_S}$$

$$= \frac{20-12}{330} = 0.024\,A$$

12. A power supply produces an output d.c. voltage of 25V. Draw the circuit diagram for getting output of 15V, 15.7V and 16.4V.

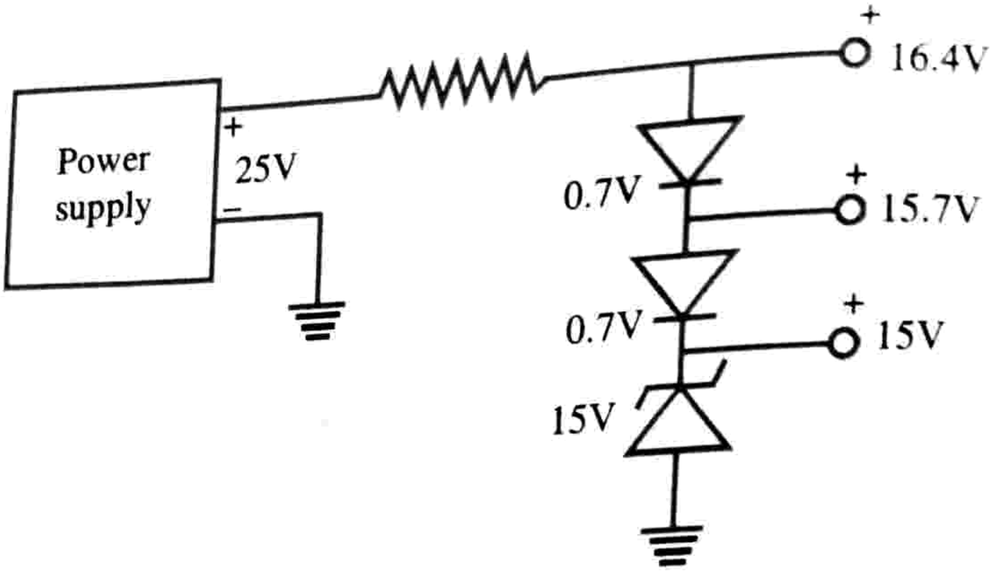

Fig. 1.24

13. A zener diode shown in fig. has $V_Z = 18V$ as long as I_Z is maintained between 200mA and 2A. Find the value of series resistance R so that E_0 remains 18V while input voltage E_i is free to vary between 22V to 28V (CU Nov. 18)

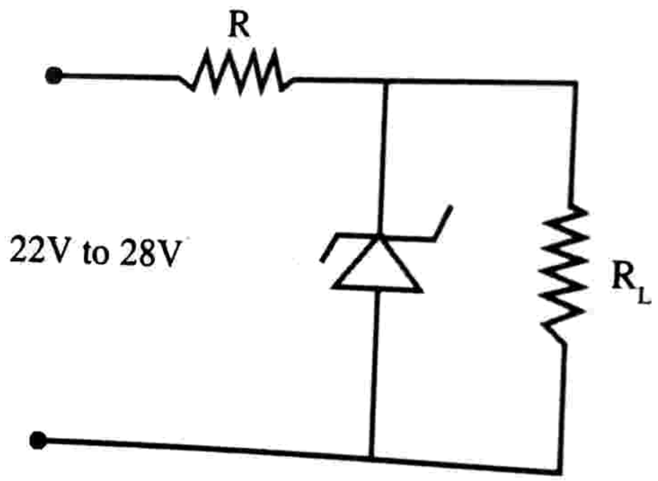

Fig. 1.25

Ans: Zener current is minimum (200mA) when input voltage is minimum (22V)

Load current (which is constant) $I_L = \frac{V_Z}{R_L} = \frac{18}{18\Omega} = 1A$

$$R = \frac{(E_i - E_o)}{I_{Z\,mini} + I_{Z\,max}} = \frac{22-18}{(200+1000)mA} = \frac{4}{1200} = 3.33\Omega$$

14.

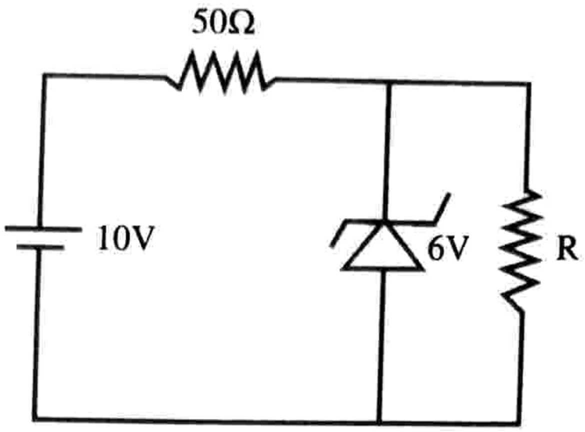

Fig. 1.26

6V zener diode has zero resistance. Its knee voltage is 5mA. Calculate the minimum value of R so that the voltage across it does not fall below 6V.

Ans: 1.2kΩ